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THE EFFECT OF MERCURY-VAPOUR PRESSURE IN A MERCURY MANOMETER.(U)
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THE EFFECT OF MERCURY-VAPOUR PRESSURE IN A MERCURY MANOMETER

David B. Prowse* and David J. Hatt

Approved for Public Release

* Previously at Materials Research Laboratories.
Now at the National Measurement Laboratory.

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(6) # THE EFFECT OF MERCURY-VAPOUR PRESSURE IN A MERCURY MANOMETER

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ABSTRACT

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16. *ABSTRACT (If this is security classified, the announcement of this report will be similarly classified):*

The effect of the pressure of mercury vapour acting on the free surfaces of the two arms of a manometer is discussed, particularly in relation to the MRL interferometric manometer.

DEFENCE RELEVANCE STATEMENT

The measurement of pressure is of defence interest both for altimetry and for monitoring fluid pressures, as well as for scientific studies. The corrections to a mercury manometer described in this paper are relevant to measurements of the highest accuracy.

THE EFFECT OF MERCURY-VAPOUR PRESSURE IN A MERCURY MANOMETER

Over the past few years there has been considerable improvement in both the accuracy and resolution of mercury manometers (see for example the list of references in [1]). Most of these manometers have accuracies approaching 1 part in 10^6 while the capacitance manometer described by Guildner et al. [2] has a resolution of 0.1 mPa and our interferometric manometer [1] has a resolution of 10 mPa [3].

The saturation vapour pressure of mercury (160 mPa at 20°C) is approximately 2 parts in 10^6 of atmospheric pressure (101 kPa) which is significant in terms of the accuracies claimed and especially at lower pressures where the uncertainty of temperature effects is less. Some authors (Guildner et al. [2], Kaneda et al. [4], and Bass and Green [5]) take into account the vapour pressure of mercury in determining the pressure measured by their manometers whereas other authors do not mention this effect. It was therefore important to decide if it was necessary to allow for the vapour pressure of mercury in absolute pressure measurement with our interferometric manometer.

In normal use both arms of the manometer are evacuated with a vacuum pump (either sorption or ion pump) and are connected by a valve which, when shut, isolates the measuring arm from both the pump and the reference arm. With the valve closed, gas is admitted to the measuring arm while the reference arm continues to be evacuated by the pump.

To measure the effect of the vapour pressure both arms of the manometer were evacuated by the ion pump through a liquid-nitrogen cold trap, and the output from the interferometer was obtained, via a digital-to-analog converter, on a chart recorder. The chart-recorder reading was set to zero and the valve connecting the two manometer arms was then closed.

When the valve was closed no initial change in the chart-recorder reading occurred. However, the reading increased linearly with time so that after 7 hours a reading of 8 fringes was recorded (equivalent to a pressure of 340 mPa). When the valve was opened at the end of this time the reading immediately returned to zero. The increase in pressure was due to small leakage in the system, since, had it been caused by the vapour pressure of mercury, the chart-recorder would have reached a steady value between 0 and 4 fringes very quickly (approximately 0.1 s as discussed below). In fact, however, except for a small momentary increase in pressure after the valve

was opened the ion pump current indicated a pressure of 13 μPa throughout the experiment.

A simple calculation with Diels and Jaeckel's [6] value for the rate of evaporation of molecules (1.42×10^{21} molecule/m^2.s) indicates that in our manometer (35 mm diameter tubing, 1 m long connected to each arm) the saturation vapour pressure of mercury should be established in a time of the order of 0.1 s. If this value is used to calculate the volume of mercury lost during evacuation a value of 30 mm^3/h, much higher than actually occurs, is obtained; thus it appears that saturation vapour pressure is not reached near the pump.

These results show that under 'vacuum' the saturation vapour pressure of mercury, P_s, acts on the mercury surfaces in the two arms of our manometer (to an accuracy of 10 mPa - the resolution of the manometer) and that this pressure is not influenced by pumping with a vacuum pump. However when the measuring arm is connected to a comparison instrument, the vapour pressure at this instrument may, or may not, be the saturated vapour pressure of mercury, depending on the geometry of the connecting tubing. Kinetic theory states that the pressure in a closed system of constant and uniform temperature is proportional to the number of gas molecules, is independent of the nature of the gas and that equilibrium in pressure is established when there is no nett transfer of molecules to or from any region. If nitrogen is leaked into the measuring arm so that the pressure is in the viscous flow region (greater than approximately 1.3 Pa, where the transition from molecular to viscous flow occurs) then flow will occur until equilibrium as defined above is established and the pressure P at the comparison instrument will be equal to the pressure at the mercury surface. Thus, apart from altitude effects, the pressure P is balanced by the height of the mercury column h (measured by the interferometer) and P_s acting on the mercury surface in the reference arm, giving

$$P = P_s + \rho gh$$

Initially there may be concentration gradients of mercury vapour and nitrogen but mixing by diffusion will occur at uniform pressure and the total pressure in the system will slowly increase as the vapour pressure of mercury increases to the saturation vapour pressure throughout the system. (As shown in [7] this should take approximately 10 hours).

For the molecular-flow region (pressures less than approximately 1.3 Pa), if a cold trap is placed between the manometer and the comparison instrument then, as shown in [8], the presence of the cold trap does not affect the pressure of any non-condensable gas at either instrument. In this case P_s cancels out and the absolute pressure is given directly by the number of counts on the manometer,

$$P = \rho gh,$$

provided that equilibrium has been established.

Hence, as the saturation vapour pressure of mercury always acts on the mercury surface in the reference or 'vacuum' arm of our manometer, to obtain absolute pressure it is necessary to add the value of the mercury vapour pressure (160 mPa) to the pressure determined from the height difference between the two surfaces. This result applies for the region of viscous flow; but for molecular flow, if a cold trap is used, then the pressure is given by the height difference between the two surfaces. These results should apply to most other mercury manometers, but are significant only for measurements of very high precision.

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